MAGNETIC ARRAY POSITION SENSOR

Technical Field

[0001] The invention relates to position sensors and, more particularly, to position sensors using a magnetic linear array.

Background of the Invention

[0002] Galvanomagnetic sensing elements, such as Hall generators and different types of magnetoresistors (MRs), are widely used in automotive and industrial position and speed sensors. They can operate in most environments as they are relatively unaffected by dirt, most chemicals, oils and other lubricants. They can operate up to reasonably high temperatures (150 or 200 degrees C) depending on the sensing device material.

[0003] The majority of these sensors use one, or at most two, sensing elements. Sensors with a single sensing element are the simplest, but also the least accurate. Sensors with two matched sensing elements spaced some distance apart from each other are used in a differential mode, whereby common mode disturbances are rejected. Two element sensors operating in differential mode provide better accuracy than single element sensors. Since they are capable of locating with high accuracy a particular feature of the sensed object, such as a tooth edge or a center of a slot, such differential sensors are often used as incremental (on-off) sensors, e.g., as crankshaft position sensors. The differential sensor, however, cannot maintain the same high accuracy if it is used as a linear sensor, providing a continuous analog output signal proportional to displacement. This is especially true where relatively large displacements, i.e., those on the order of five mm or higher, are measured.

Summary of the Invention

[0004] A highly accurate sensor is needed that can be used as a common building block for a variety of specific continuous analog sensors with 0.1% or better accuracy, whether measuring angular or linear position. One embodiment of the present invention is a magnetic position sensor for measuring a linear position or an angular position of a device. The sensor includes a linear array of galvanomagnetic

sensing elements mounted upon a surface of a magnet fixedly mountable adjacent the device. The sensor also includes a target connectable to the device such that the target moves adjacent a surface of the array in response to movement of the device. The target is shaped so that a magnetic flux density curve resulting from excitation of the sensing elements includes a peak and/or a valley. A first circuit is used for exciting each of the sensing elements, and a second circuit is used for measuring a magnetic flux density value at each of the sensing elements. Each magnetic flux density value is associated with the magnetic flux density curve. A maximum of the peak and/or a minimum of the valley indicates the linear or angular position of the device.

[0005] A second embodiment of the present invention is a method of measuring a linear position or an angular position of a device. The method includes the step of fixedly mounting a magnet adjacent the device, wherein a linear array of galvanomagnetic sensing elements is mounted upon a surface of the magnet. The method also includes the step of connecting a target to the device such that the target moves adjacent a surface of the array in response to movement of the device. The target is shaped so that a magnetic flux density curve resulting from excitation of the sensing elements includes a peak and/or a valley. Finally, the method includes the steps of exciting each of the sensing elements and measuring a magnetic flux density value at each of the sensing elements. Each magnetic flux density value is associated with the magnetic flux density curve and a maximum of the peak and/or a minimum of the valley indicates the linear or angular position of the device.

[0006] Many variations in the embodiments of present invention are contemplated as described herein in more detail. Other applications of the present invention will become apparent to those skilled in the art when the following description of the best mode contemplated for practicing the invention is read in conjunction with the accompanying drawings.

Brief Description of the Drawing

[0007] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

[0008] Figure 1 is a top schematic view of an array sensor in accordance with the present invention;

[0009] Figure 2 is a graph of the magnetic image resulting from the array sensor according to Fig. 1;

[0010] Figure 3A includes cross-sectional views of three target configurations that can be used in accordance with the present invention to produce a magnetic flux density curve having a peak;

[0011] Figure 3B includes cross-sectional views of two target configurations that can be used in accordance with the present invention to produce a magnetic flux density curve having a valley;

[0012] Figure 4 is a circuit diagram including a circuit for exciting a Hall element sensor array and a circuit for measuring the resultant magnetic flux density through the array elements;

[0013] Figure 5 is a circuit diagram including a circuit for exciting a magnetoresistor sensor array and a circuit for measuring the resultant magnetic flux density through the array elements;

[0014] Figure 6 is a cross-sectional view of an array sensor according to Fig. 1 with a graph illustrating the three-point parabola fit method of the present invention;

[0015] Figure 7 is an illustration of the use of the linear array according to Fig. 1 in a linear sensor;

[0016] Figures 8A-8C are illustrations of the use of the linear array according to Fig. 1 in an angular sensor;

[0017] Figure 9 is a plan view of a target of the linear sensor according to Fig. 7 with the inclusion of side offset compensation;

[0018] Figure 10 is a plan view of a target of the angular sensor according to Fig. 8 with the inclusion of eccentricity compensation;

[0019] Figure 11 is a graph representative of the magnetic flux density curve resulting from the sensor according to either Fig. 9 or Fig. 10;

[0020] Figure 12A is a cross-sectional view of an array sensor including a dual target shown with a graph of the magnetic image resulting from the array sensor at three positions of the dual target along the surface of the magnet; and

[0021] Figure 12B is an illustration of the use of an array sensor in accordance with Fig. 12A in a linear sensor.

Description of the Preferred Embodiment

[0022] The use of a magnetic array position sensor as a continuous analog sensor to measure either angular or linear position are shown in the drawing with reference to Figures 1-12. The basic principles are illustrated starting with Figs. 1-5. Figure 1 shows an array sensor 10 that can be used in the present invention. The sensor 10 includes a linear array 12 mounted on a bias magnet 18. Alternatively, an electromagnet can be used in place of the bias magnet 18. The array 12 is linear, i.e., it comprises a plurality of roughly identical and equidistantly-spaced galvanomagnetic sensing elements 14 on a single die 16. Of course, more than one die 16 can also be used to form the linear array 12. The sensing elements 14 of the linear array 12 can be Hall elements or magnetoresistive elements, by example. Details of the construction of one linear array 12 that can be used in the present invention are disclosed in U.S. Patent No. 6,201,466, the entire contents of which is incorporated herein by reference. In the example of Fig. 1, the linear array 12 has sixteen sensing elements 14 spaced equidistantly by a value d along the length of the linear array 12. The sensing elements 14 are identified as array element numbers 0-15. The total distance between the first and last array elements, array element numbers 0 and 15 in this example, is indicated by a distance D.

[0023] Figure 1 also shows a target in the form of a magnetic strip 20 movably supported in a non-magnetic block 24 (shown in Figs. 3A and 6) above the linear array 12. The target can be one of a variety of configurations, as discussed in more detail below. The target is typically supported by a target assembly (not shown).

The bottom of the target is located above the top surfaces of the sensing elements 14, defining an air gap 19 (shown in Fig. 6). Although described as an "air gap," the air gap 19 between the target and the sensing elements 14 does not necessarily exist as empty space. An overmolding layer protecting the sensor array 12 and a protective coating for the target and target assembly, if used, are magnetically indistinguishable from air and comprise part of the air gap 19. The strip target 20 in this example is narrower than the spacing d between the sensing elements 14 and moves in the directions indicated by the arrows A and B in response to the movement of a device to which it is attached.

[0024] As mentioned, the target can be one of a variety of configurations. The only requirement for the target is that its presence at a position above the linear array 12 will result in a peak or valley in the magnetic flux density sensed by the array elements 14. This peak or valley should be roughly symmetrical about the location of the respective maximum or minimum. For example, Fig. 2 graphs the component of magnetic flux density normal to the length of the array 12 and the magnet 18 of Fig. 1. While the whole magnetic flux density curve is not symmetrical about the location of the maximum, a roughly symmetrical peak is shown about the location of the strip target 20 between sensing element numbers 5 and 6. Figure 2 will be discussed in more detail hereinafter. Locating the highest point in a peak, or the lowest point in a valley, indicates the relative position movement of the device to which the target is attached, and thus its linear or angular position.

[0025] Example configurations for the target are shown in Figs. 3A and 3B. Figure 3A shows two configurations that will result in a peak, in addition to the familiar target comprising the magnetic strip 20 in the non-magnetic block 24. The target shown at the top of Fig. 3 comprises a magnetic tooth 21 extending toward the array 12 from an integral magnetic mount, here a block. At the bottom of Fig. 3, the target is a narrow magnet 23 movably mounted above the array 12. In this embodiment, the array 12 is mounted upon a magnetic base 25. Any target that results in a peak is generically referred to herein as a magnetic tooth. Two configurations for a target that will produce a valley when the target is in the

presence of the array 12 are shown in Fig. 3B. At the top of Fig. 3B, a magnetic slot 22 is located in a magnetic mount, block 26. The target at the bottom of Fig. 3B is a slot 27 extending from a nonmagnetic mount, where two magnetic strips or blocks 29 embedded in the nonmagnetic mount form the slot 27. Any target that results in a valley is generically referred to herein as a magnetic slot.

[0026] A magnetic tooth or slot whose presence at a position above the linear array 12 will result in a peak or valley when viewing the magnetic flux density generated by the magnet 18 and sensed by the array elements 14 is desirable. This is because the position of the peak or valley, i.e., the location of the maximum or minimum voltage is immune to air gap variations. In contrast, the highly nonlinear relation between magnetic field density and the size of an air gap affects the magnitude and the slope of the magnetic image of a tooth edge and, hence, the location of any predetermined point on the slope that could be used as a reference point, e.g., the midpoint, in determining target position. Other characteristics of the target will be discussed in further detail herein.

[0027] Processing circuitry is operatively connected to the linear array 12 according to known methods to excite the sensing elements 14. The processing circuitry is also capable of scanning a voltage potential across each of the sensing elements 14 and digitizing these scanned output signals. The voltage potential across each of the sensing elements 14 is directly related to, and thus can be used to represent, the component of magnetic flux generated by the magnet 18 normal to the length of the magnet at that point. The processing circuitry can be a microprocessor or a digital signal processor (DSP) or the like connected to the linear array 12 by leads or integrated with the linear array 12 on the same die 16. The processing circuitry preferably includes memory, but it could be connected to external memory capable of storing the digitized data and storing a program including one or more algorithms, described in further detail herein, to determine the precise position of the movable target or portion of the target facing the linear array 12 by locating the maximum or minimum value of the curve created by the individual voltage potentials.

[0028] Two examples of processing circuitry that can be used to measure the voltage potential are shown in Figs. 4 and 5. Figure 4 shows processing circuitry 30 that can be used when the linear array 12 comprises a plurality of sensing elements 14 in the form of Hall elements. There are n sensing elements, labeled Hall #0, Hall #1, . . . Hall #i, . . . Hall #n-1. Excitation of the sensing elements 14 can be performed by many different circuit designs. In this embodiment, excitation is performed by a voltage supply 32. Each sensing element 14 is connected to the voltage supply 32.

[0029] The remainder of the processing circuitry 30 provides a circuit for acquiring the measurement of this magnetic flux density for each array element 14 and for determining the peak from at least some of those measurements. As the voltage from the voltage supply 32 is applied across each of the sensing elements 14, Hall #0, Hall #1, . . . Hall #i, . . . Hall #n-1, leads from each of the sensing elements 14 delivers the Hall voltage and provides each Hall voltage signal to respective channels, Channel 0, Channel 1, . . . Channel i, . . . Channel n-1, of a multiplexer 34. The multiplexer 34 provides an output voltage associated with each channel number to a microprocessor 36 for additional processing and/or display. The additional processing includes, for example, the determination of the maximum (or minimum) of the curve fitted to the measured values as described in more detail herein. The microprocessor 36 can be, for example, part of a standard engine controller. In any case, memory may be required for storing the output data.

[0030] Of course, other processing circuitry known to those of skill in the art can be used to excite a magnetic element and measure magnetic flux density. For example, Fig. 5 shows processing circuitry 40 that can be used when the linear array 12 comprises a plurality of sensing elements 14 in the form of magnetoresistive (MR) elements. Like in Fig. 4, there are n sensing elements 14, labeled MR_0, MR_1, . . . MR_i, . . . MR_{n-1}. Excitation of the sensing elements 14 can be performed by any number of circuit designs. In this embodiment, excitation is performed by one or more current sources 42. Each sensing element 14 is connected to a current source 42 by a lead.

[0031] The remainder of the processing circuitry 40 provides a circuit for acquiring the measurement of this magnetic flux density for each array element 14 and for determining the peak from at least some of those measurements. As the current from a current source 42 flows into each of the sensing elements 14, MR_0, MR_1, . . . MR_i, . . . MR_{n-1}, a lead from each of the sensing elements 14 detects a voltage drop and provides each voltage drop to respective channels, Channel 0, Channel 1, . . . Channel i, . . . Channel n-1, of a multiplexer 44. The multiplexer 44 provides an output voltage associated with each channel number to a microprocessor 46 for additional processing and/or display. As described with respect to Fig. 4, the additional processing includes, for example, the determination of the maximum (or minimum) of the curve fitted to the measured values as described in more detail herein. Again, the microprocessor 46 can be part of a standard engine controller or a stand-alone microcontroller. In any case, memory may be required for storing the output data.

[0032] As mentioned, Fig. 2 graphs the voltage measured for each of the sensing elements 14 of the linear array 12 of Fig. 1. The magnetic strip target 20 is located at a known position of 850 microns from array element number 0. The strip target 20 is a 0.1 mm-thick blade narrower than the spacing d between adjacent sensing elements 14. The spacing d is 160 microns, and the width of the strip target 20 is 100 microns, by example. The air gap 19 defined by the distance between the bottom of the strip target 20 and the top surfaces of the sensing elements 14 is 0.2 mm, by example. The magnet 18 needs to be thick enough to generate a magnetic flux sufficient for a peak to be detected in the presence of the target. By example, the magnet 18 is about five millimeters thick. In Fig. 2, the maximum in the measured voltage is between the element numbers 5 and 6 of the sensing elements 14. By interpolation, the strip target 20 is between array element numbers 5 and 6 centered at position 5.3215 (850 μm/160 μm).

[0033] It is desirable that the target be comparable in width to the spacing d between adjacent sensing elements 14, because, depending upon the spacing d of adjacent sensing elements 14, this yields a relatively accurate sensor 10. Even more

desirable is a target narrower than the spacing d. However, as the target becomes narrower, it is more likely to be damaged, and too narrow a target will saturate. These factors must be balanced with the goal being merely to produce a peak or valley in the magnetic flux density waveform that is roughly symmetrical about the location of the maximum or minimum value. It is also worth noting that the strip target 20, like other targets resulting in a peak, is typically narrower than, and extends further in a direction normal to the length of the magnet 18 (the "depth"), than a target needed to achieve a valley having the same magnetic profile as the peak. For example, to produce a valley having the same magnetic profile as the curve of Fig. 1 using a slot target 22 in a magnetic block 26, the slot target 22 would have a depth of 1.0 mm and a width of about 0.5 mm. In this case, the graph would be a valley with a minimum voltage at the position of the slot target 22.

[0034] Although the position of the strip target 20 was known in the example of Fig. 2, the sensor 10 is designed to be used where the position of a target is the unknown. With targets in the form of magnetic teeth, such as those shown in Fig. 3A, the highest point of the peak in the magnetic flux density curve is at the location, or center, of the target. Conversely, with magnetic slot targets such as that shown in Fig. 3B, the lowest point of the valley that represents the magnetic flux density curve is at the location, or center, of the target. This highest or lowest point can be determined analytically by fitting a function having a peak or valley, e.g., cosine, sine, or a 2^{nd}-order or higher polynomial, to several of the measurements obtained from sensing elements 14 closest to the peak and then computing the location of the maximum (or minimum) of the function.

[0035] However, the fitting of some functions requires far more computation than that of others without improved accuracy. Testing shows that very accurate results can be obtained by fitting a parabola to just three points -- three sequential values of the measured flux density value that include the highest point measured when the magnetic flux density curve includes a peak (or the lowest point measured when the magnetic flux density curve includes a valley). In this case, the position P of the maximum or minimum of the curve can be computed directly, without using a

regression method. The interpolated position P corresponding to the location of the target along the length of the array 12 relative to the array element numbers is given by the following formula:

$$P = .5\left(\frac{j_1^2(V_3 - V_2) + j_2^2(V_1 - V_3) + j_3^2(V_2 - V_1)}{j_1(V_3 - V_2) + j_2(V_1 - V_3) + j_3(V_2 - V_1)}\right); \text{ where}$$

j_1 is the array element number of the highest or lowest measured voltage, where a measured voltage V_1 represents the magnetic flux density value at the array element j_1;

j_2 is a second array element number in a sequence of three array elements including array element number j_1;

j_3 is a third array element number in the sequence of three array elements including array element number j_1;

V_1 is the highest or lowest measured output voltage;

V_2 is the output voltage associated with array element number j_2; and

V_3 is the output voltage associated with array element number j_3.

[0036] Several examples can be provided using an array 12 with n array elements and where the first array element is i=0 and the last array element is i=n-1. If the first array element 0 senses the highest (or lowest) field, array element numbers 0, 1 and 2 and their associated output voltages can be used. Similarly, if the last array element n-1 senses the highest (or lowest) field, array element numbers n-1, n-2 and n-3 and their associated output voltages can be used. Another example is shown in Fig. 6.

[0037] Figure 6 shows the derivation of the peak P and the position of the magnetic strip target 20 using this three point parabola fit method when the highest or lowest field is measured somewhere other than the first or last array element 14. In Fig. 6, similar to Fig. 1, a freely-movable magnetic strip target 20 is positioned above a linear array 12 mounted on a magnet 18. The strip target 20 is shown centered on and supported by a nonmagnetic slider 24. An air gap 19 separates the target 20 from identical sensing elements 14 equidistantly spaced at a distance d of 160 microns. There are n sensing elements 14, which are designated in the graph as

array element number i=0 to array element number i=n-1. The highest measured voltage V_1 is associated with i=2, that is, array element number 2. In the example shown, array element i-1, i.e., array element number 1, and array element i+1, i.e., array element number 3, are used in the above formula, together with their associated output voltages, V_2 and V_3, respectively. Thus, the position P of the voltage peak relative to the position of the array elements can be determined. Herein, we assume that the formula yields a value P of 1.67. The strip target 20 is located at a location L relative to the position of the first array element, such as array element number 0. The location L is determined from the following equation:

[0038] $L = P \times d$; where

L is the location of the target 20 along the linear array 12 relative to the position of the first array element;

P is the position of the maximum or minimum measured voltage along the length of the linear array 12 relative to the sensing elements 14; and

d is the distance between adjacent sensing elements 14 of the linear array 12.

Thus, in the example of Fig. 6, the location L is equal to 267 microns (1.67 x 160 μm).

[0039] Notice, however, that there is more than one sequence of three array elements that include array element number 2 (i=2). Another sequence of three array elements that includes array element number i=2 also includes array element numbers i-1 and i-2, array element numbers 1 and 0, respectively. Yet another sequence of three array elements that includes array element number i=2 also includes array element numbers i+1 and i+2, array element numbers 3 and 4. It has been shown that even more accurate results can be obtained using the three point parabola fit method, when possible, by calculating two positions P using two separate sequences, then averaging the two positions P. Although up to three sequences are available where the highest or lowest field is measured somewhere other than the first or last array element 14, any additional accuracy due to the inclusion of the third sequence in the calculation of position does not appear to justify the additional computation required.

[0040] The linear array 12 described can be used in high accuracy linear and angular position sensors as shown in Figures 7-10. Figure 7 shows a linear array 12 where a strip target 50 is positioned at a fixed angle α with respect to the direction of displacement of the strip target 50. For simplicity, the magnet 18 and the supporting block are not shown. As the block supporting the strip target 50 is displaced in the directions indicated by the arrows E and F, the strip target 50 freely moves between sensing elements 14 of the linear array 12 in the directions indicated by the arrows A and B in Figs. 1 and 6. The linear range R of this linear sensor 10a is determined by the following formula:

[0041] $R = D / \sin \alpha$; where

R is the linear range of the linear sensor 10a;

D is the distance between the first and last sensing elements 14; and

α is the angle of the strip target 50 with respect to the direction of displacement of the strip target 50.

[0042] In Fig. 7, where D equals 2.0 mm and the angle α equals five degrees, the linear range R is equal to 22.9 mm (2.0 mm/sin 5°). The location of the strip target 50 along the length of the linear array 12 can be determined as described with reference to Fig. 6. Because the motion normal to the linear array 12 is reduced in the configuration of Fig. 7, the configuration allows the same linear range R of the sensor 10 while using a linear array 12 of a shorter length. A linear sensor, such as sensor 10a shown in Fig. 7, can be used in a variety of applications and devices. For example, such a sensor can be used for body height sensing in shock absorbers. Another application can be to measure the relative movement of a piston in a master cylinder. A linear sensor according to the present invention can also be used to measure the movement of a seat by mounting the linear array 12 on the stationary rail of a seat and by mounting a target to the movable seat. Many other applications of a linear sensor incorporating the present invention are possible.

[0043] Figures 8A-8C shows the linear array 12 being used in an angular position sensor 10b. The sensor 10b measures the rotational angle of a rotating shaft 31 in, for example, a motor. A spiral magnetic tooth or slot forms the target. Here,

the target is a spiral magnetic strip 52 mounted on an annular non-magnetic disk 54. Of course, other target configurations using an annular mount are possible. The disk 54 is fixedly mounted to the shaft 31 such that the disk 54 rotates with the shaft 31 about a rotational axis 28. The linear array 12 is fixedly mounted adjacent the disk 54 so that the sensing elements 14 face the spiral target 52. For example, in a motor, the linear array 12 can be mounted on the stator according to known methods. As the disk 54 rotates, the spiral target 52 transverses the linear array 12. Each location of the spiral target 52 along the length of the linear array 12 corresponds to a unique angle of rotation such that:

[0044] $R(\beta) = r + \beta\,(R-r) / 360°$; where

$R(\beta)$ is the radius of the spiral target 52 at an angle of rotation β;

R is the known maximum radius of the spiral target 52; and

r is the known minimum radius of the spiral target 52.

[0045] The range of movement of the spiral target 52 is equal to R-r. Preferably, then, the length of the linear array 12 is designed so that it is slightly longer than the range (R-r) such that the spiral target 52 travels from about the midpoint between the first and second sensing elements 14, array element numbers 0 and 1, and about the midpoint between the last two sensing elements 14, array element numbers n-2 and n-1, wherein n is the number of sensing elements 14. The processing circuitry, such as that shown in Figs. 4 and 5, generates a linear function of the angle α. It can also compute and output, in addition to the angle β, any desired function or functions of the angle β required in particular applications, e.g., sin β, cos β. sin 3β, etc. A graph of the magnetic image resulting from the angular sensor of Figs. 8A-8C is similar to that shown in Figs. 2 and 6.

[0046] Linear position sensors in industrial and automotive applications are often affected by inadvertent fixed or variable side offsets of the target due to, for example, the tolerance(s) of assembly parts or due to the target being bent over time. Similarly, angular position sensors in industrial and automotive applications are often affected by eccentricity errors caused by imprecise or worn out shafts, bushings or bearings. Thus, it is desirable that the linear position sensor 10a and the angular

position sensor 10b be immune to or otherwise capable of compensating for these errors. Figure 9 shows a portion of the linear position sensor according to Fig. 7 modified to include side offset compensation. In this embodiment, the strip target 50 is embedded in a non-magnetic block 58. A second magnetic strip is a second target 56 that is also embedded in the non-magnetic block 58. The reference strip target 56 travels linearly in the direction of movement of the non-magnetic block 26 (in the direction of arrows E and F). This reference strip target 56 is a reference for compensating for side offset-related errors, as discussed in more detail below.

[0047] Figure 10 shows the addition of a reference track to the disk 54 of Fig. 8. Here, the reference track is a circular target 60 comprising a second magnetic strip concentric with the spiral target 52. The circular target 60 acts as a reference track for compensating for eccentricity-related errors. Although shown in Fig. 10 as located radially inside the spiral target 52, it can be located radially outside the spiral target 52. The circular reference target 60 is read by the first three sensing elements 14 of the linear array 12, while the spiral measuring target 52 is read by array element number 3 through array element number n-1, depending on the angular position, where n is the number of sensing elements 14 and the first sensing element 14 is array element number 0.

[0048] Figure 11 is a graph representative of the magnetic flux density curve resulting from either a linear sensor in accordance with Fig. 9 or an angular sensor in accordance with Fig. 10. Each measuring target, strip target 50 in Fig. 9 or spiral target 52 in Fig. 10, and reference target, reference strip target 56 in Fig. 9 or circular reference target 60 in Fig. 10, produces a peak. Either of the reference targets 56, 60 will produce a stationary peak 62 with respect to the linear array 12 when there is no side offset or eccentricity. The measuring targets 50, 52 produce a moving peak 64 with respect to the linear array 12. The location of the maximum of each peak 62, 64 can be determined by any of the curve-fitting methods mentioned previously. The presence of a side offset or eccentricity affects both targets equally. Thus, the effect of a side offset or eccentricity can be completely eliminated by using the difference in the maximum locations as the measure of linear or angular position.

[0049] Because a larger die 16 is needed as the number of magnetic sensing elements 16, such as MRs or Hall sensors, increase, the cost of producing a basic array position sensor 10 as described with respect to Figs. 1-5 capable of measuring ever larger displacements increases. While the length of the linear array 12 defines the dynamic range R of the array sensor 10, accuracy and resolution depend on the distance d between sensing elements 14 and the algorithms used in interpolating the peak. Thus, one way to increase the dynamic range R while maintaining the same absolute accuracy is to lengthen the linear array 12 and proportionally increase the number of sensing elements 14. This not only increases the cost of the die, but also the complexity and cost of the processing circuitry. It is unlikely that automotive or other industrial applications can justify the cost of dies accommodating linear arrays longer than some three mm.

[0050] One method of extending the range of a linear array for linear applications has been described previously in Fig. 7. Another method of extending the range of a linear array to use a dual target as is shown in Figs. 12A and 12B. The embodiment of the dual target shown in Fig. 12A comprises two parallel magnetic strip targets 66, 68 separated by a distance D_T in a non-magnetic block 70. Of course, the dual target can be any of the other target configurations described as long as each target produces a magnetic profile having a peak or valley. In this embodiment, each target 66, 68 is wider than the distance d between adjacent sensing elements 14, by example. Preferably, the distance D_T is less than or equal to D/2, half of the distance between the first and last sensing elements 14. This extends the dynamic range of the sensor to approximately D*2 without increasing the length of the linear array 12.

[0051] The presence of the two strip targets 66, 68 results in a magnetic profile in the linear array 12 having a distinct first peak 72 and a distinct second peak 74, with a valley 76 between the two peaks 72, 74. The distance D between the strip targets 66, 68, is such that the linear array 12 experiences at least one of the peaks 72, 74 at all times. When the non-magnetic block 70 is in its leftmost position (in the direction of the arrow A), the second peak 74 is located at the beginning of the linear

array 12. The processing circuitry recognizes that the peak is the second peak 74 because it is not followed by the valley 76. As the dual target on the non-magnetic block 70 moves in the direction indicated by the arrow B, the second strip target 68 moves toward the middle of the linear array 12. The processing circuitry identifies the peak as the second peak 74 by its detection of the valley 76 to the left of the peak. The locations of the maximum of each of the peaks 72, 74 and the minimum of the valley 76 can be determined by any of the curve fitting methods mentioned above.

[0052] Figure 12B shows a practical implementation of the principles of Fig. 12A in a modified linear sensor based upon Fig. 7. Figure 12B shows a linear array 12 where each strip target 50, 80 of a dual strip target are embedded in a non-magnetic block 78 and are positioned at a fixed angle α with respect to the direction of displacement of the strip targets 50, 80. For simplicity, the magnet 18 is not shown. As the block 78 supporting the strip targets 50, 80 is displaced in the directions indicated by the arrows E and F, the strip targets 50, 80 freely move between sensing elements 14 of the linear array 12 in the directions indicated by the arrows A and B in Figs. 1 and 6.

[0053] The use of an array, and particularly a linear array 12, of sensing elements increases sensor accuracy over differential sensors by decreasing the interpolation range between sensing elements and by permitting the use of nonlinear curve-fitting algorithms that require only relative values of the output signals from the sensing elements.

[0054] The sizes mentioned herein for the target, magnet, spacing d and length D are by example only. A linear array with a long length D is more expensive. The smaller the spacing d, the more accurate the sensor for the same length D of the linear array since it has more sensing elements. However, the smaller the spacing d, the smaller the air gap should be. Thus, assembly tolerances become an issue. The balance between tight tolerance requirements, accuracy and size, which equates directly to price, is application-specific and can be determined by one of skill in the art based upon the teachings herein.

[0055] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.